

Center for Nondestructive Evaluation – Iowa State University

The **Center for Nondestructive Evaluation (CNDE)** was established in 1985 as a **NSF Industry/University Cooperative Research Center**. NDE plays an important role in ensuring the safe use of engineered systems ranging from offshore oil facilities miles below the sea, to bridges and roadways we drive on every day, to planes that carry both the public and defense personnel. CNDE has a long history of working with industry to provide cost-effective tools and solutions which address relevant problems for a variety of industrial sectors which include:

Aerospace (commercial and military aviation) **and Defense Systems** (ground vehicles and personnel protection); **Energy** (nuclear, wind, fossil); **Infrastructure and Transportation** (bridges, roadways, dams, levees); and **Petro-Chemical** (offshore, processing, fuel transport piping). Industrial partnerships with nearly 100 companies have included the NSF Industry/University Cooperative Research program, single-company proprietary projects, multi-company collaborations, and CNDE-led consortia.

With over 30 scientists and engineers, CNDE is the premier US research organization for the development and application of inspection and sensing technologies. Among many accomplishments is development and commercialization of **simulation models** for the three major inspection modalities, eddy current (ECSIM), ultrasonics (UTSIM), and radiography (XRSIM), which are used in inspection optimization, detectability studies and training. Additionally, extensive **materials characterization studies** and **inspection system developments** have been applied and implemented for metals, ceramics, and composites of interest to a number of industrial sectors. Experimental and theoretical capabilities are available for the full range of inspection methods, housed in a 52,000 sq. ft. facility with over \$5M in state-of-the-art research instrumentation that includes electromagnetics, radiography, thermal, terahertz, and ultrasonics. A growing **NDE education program** is also in place which includes an undergraduate NDE Minor and a graduate certificate which is available as a distance education option. A variety of government and industrial funding sources have supported major accomplishments over the past 30+ years.

At the heart of CNDE's successes, has been the NSF IUCRC, a shared, cost-effective corporate research laboratory with functions that include basic research, development and technology transfer. The program generates pre-competitive, generic results which are shared by the IUCRC sponsors. A sponsorship arrangement has served the membership well for over 25 years and has the following benefits:

- Opportunity to **guide the directions of generic, pre-competitive** research that will provide the foundation for industrial technologies
 - Biannual formal Industrial Advisory Board Meeting
 - More frequent informal contacts
- **Immediate access to the results** of that work
 - Expert advice
 - Biannual technical reviews
 - Short courses

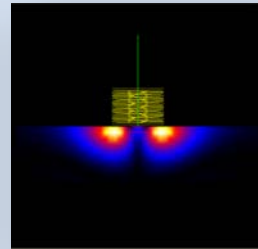
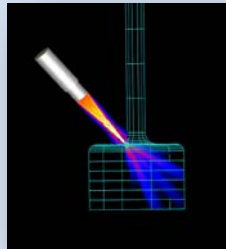
The Center for Nondestructive Evaluation was established in 1985 as one of the first NSF Industry/University Cooperative Research Centers. Since that time, CNDE has worked with over 100 companies in various capacities to apply a deep understanding of inspection physics to real problems.

- Outputs include:
 - Inspection physics
 - New inspection concepts
 - Prototype instrumentation and software
 - Inspection simulations
 - Educational programs
 - Early contact with students, including internships and prospective employees
- **A window to worldwide NDE advances**
 - Attendance at annual QNDE meeting with proceedings
 - Personal contacts with industry leaders from a variety of industrial sectors and associated perspectives
- **Opportunity to network**
 - Informal environment
 - NDE engineers from the same industry with common problems
 - NDE engineers from other industries with complementary perspectives/solutions.

CNDE sponsoring companies also have available a partner that secures funding, when the opportunity exists, to further advance items of particular, common interest. CNDE has served as a facilitator of government programs, a subcontractor to sponsors to provide technical support, and partner in jointly funded efforts. With CNDE, you have a skilled and committed team member to support applications of generic results to specific company problems in proprietary efforts as requested. Work can include ITAR/EAR compliance when required.

Nondestructive evaluation plays a critical role in the **safety and economics** of many of our

engineered systems, systems for which performance demands are ever increasing. As costly systems age, the focus turns to life extension and the desire to continue use beyond the original design goal. Inspection plays a critical role in detecting the presence of age-induced defects or damage. Simulation tools such as the ultrasonic, eddy current and x-ray examples shown in the upper right have the benefit of allowing time efficient parametric studies which allow the NDE engineer to optimize the inspection for the geometry, material systems and flaw types of interest for their specific application. The fundamental understanding of inspection physics embodied in the simulation tools and applied in innovative measurement approaches are at the heart of CNDE's accomplishments.



Government Programs: Over the past 30 years, CNDE has had a number of government funded programs that have expanded our expertise and leverage for the sponsors. Brief descriptions are provided here:

DOE BES (1980 – 1990): Development of NDE methods for application to DOE energy and weapons programs, including multi-viewing transducers for ultrasonic reconstruction of flaw size, shape, and orientation, unipolar pulser for enhanced frequency bandwidth and improved flaw reconstruction,

and novel methods for poling piezoceramic transducers to build special beam profiles (Gaussian and Bessel beams) directly into the transducer element.

US Air Force (1980 – 1993): DARPA and the USAF provided initial funding that lead to what became the CNDE. Among the developments were fundamental scattering models which served as the kernel of today's simulation tools in ultrasonics.

NSF IUCRC (1985 – present): CNDE was the eleventh IUCRC to be established and one of the four most senior programs still recognized by NSF, an honor bestowed on Center's with strong industrial support. Members of the program provide guidance on the direction of research and share access to the pre-competitive, generic research results. Membership is highly leveraged through a number of federal and state programs. Many corporate sponsors utilize CNDE expertise in proprietary projects receiving a more favorable cost structure than non-sponsors. Through ongoing participation, sponsors also have an opportunity to interact more closely with students, resulting in stronger internship and full-time employee relationships with individuals more knowledgeable of NDE.

NIST (1988 – 1998): developed and integrated simulations of inspections into a concurrent engineering approach. These developments allow NDE for the first time to be a full member of a comprehensive concurrent engineering environment called "Unified Life Cycle Engineering."

FAA (1990 – present): inspection methods for aging aircraft including crack detection, composite damage assessment, and fundamental studies of methods such as fluorescent penetrant, magnetic particle, and ultrasonics. Consortium efforts focused on jet engine inspection were completed with GE, Pratt & Whitney, Honeywell, and Rolls Royce as partners.

Iowa Companies Assistance Program (1991 – present): state-funded effort which provides NDE support to Iowa-based companies regarding NDE and materials issues. Efforts range from feasibility studies, to inspection protocol development, to longer term research collaborations, depending on the needs and interests of the company.

US Air Force (2003 – present): More recent funds have supported new methods to measure residual stress depth profiles in aerospace materials which could enable data-based retirement decisions for critical engine components; fundamental studies of vibrothermography – an emerging method for crack detection; application and improvement of simulation tools to specific AF inspection interests; and reliability studies to assess inspection efficacy.

DOE NDE for High-level Waste Storage (1995 – 2000): with the cost for hazardous waste remediation on the rise, assessment tools which would help prioritize risk and identify actual chemical make-up of storage tank and piping system contents were the focus of efforts in ultrasonics and radiography. A UT method for detection of cracking in the bottom of storage tanks was developed. The K-edge densitometry method was developed and demonstrated which enabled a determination of the contents of heavy metals (mercury, uranium, etc.) in piping systems, allowing decisions to be made regarding disposition.

DOE Nuclear Energy Research Initiative (2001 – 2005): development of NDE methods for application to next generation nuclear power systems. Efforts included characterization of high-temperature fuel pellets, and on-line NDE sensor technologies for future modular reactor concepts.

NASA (2002 – present): Novel approach to leak detection of space craft in orbit was developed. Efforts also included use of x-ray and terahertz radiation methods on the characterization of foam. The development and use of ultrasonic simulation tools for composite is currently being explored.

Army Research Lab (2008 – present): the focus of this effort has been on inspection efforts of vehicle and personnel protection. Among the accomplishments is an “effect of defects” study for vehicle armor and damage assessment for both vehicle and personnel including both body armor and helmets.

Education Programs: Education and training is an important focus of the overall CNDE efforts. Iowa State University is only US institution to offer an NDE minor at the undergraduate level with 20 to 30 students typically enrolled in the program. In 2011, a graduate level certificate in NDE became available thru on-line learning, also a first in the nation offering. CNDE also has a number of specific training developments including programs for FAA Aviation Safety Inspectors and Certification Engineers and materials for use internally at companies. A short course is offered annually to IUCRC sponsor as part of their membership. A major accomplishment of the CNDE programs is the NDT Resource Center, the NDE website used by over 300,000 users per month. Through this website, new educational materials with high quality graphics and interactive content have been made available to the NDT community. To raise awareness of NDT as a career field, science-based educational materials and career information were also developed for junior and senior high school students. With details at www.ndt-ed.org, the site is recognized as the resource for students, technicians and engineers.

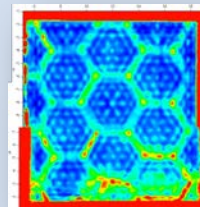


Personnel: CNDE staff includes a mix of faculty and full-time scientists and engineers as well as students at the undergraduate and graduate levels. The benefits of this arrangement are that technical resources can be available to our industry partners when they are needed without the constraints that occur with teaching appointments. In addition to the technical staff at CNDE, access to resources in the College of Engineering, Statistics, Physics, the DOE Ames Laboratory, and other relevant departments on campus are easily made available.

Facilities: CNDE includes experimental resources in excess of \$5M with brief details provided below for each of the major methods:

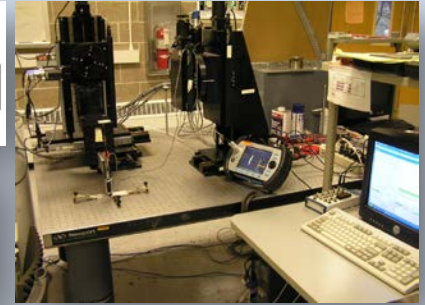
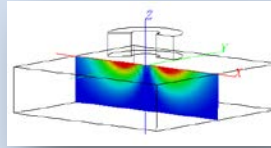
Ultrasonics:

- Six immersion scanning systems including turntables, billet rotator, dual axis bridge
- Air-coupled UT
- Phased array UT including three lab based systems, a medical UT system, and portable instrument
- Portable instrumentation for contact inspection



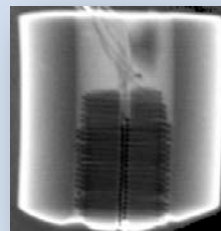
Eddy current and microwave inspection:

- Motion-controlled scanning for careful laboratory studies using impedance analyzers (up to 110 MHz) and commercial eddy current instruments (15 MHz)
- Swept frequency apparatus for surface material characterization, consisting of proprietary instrumentation up to 60 MHz and model-based inverse procedure
- Low frequency nonlinear EC method of case depth characterization in steel
- Anritsu 37347C vector network analyzer for microwave testing up to 20 GHz



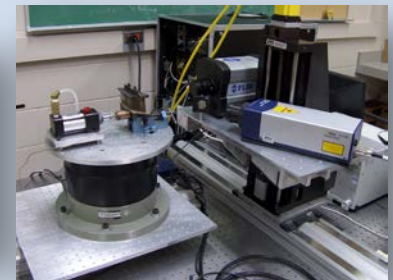
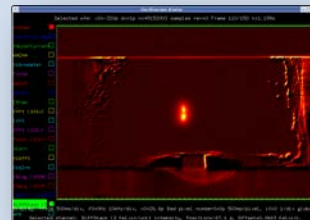
Radiography:

- Five x-ray inspection facilities including three microfocus tubes and two standard x-ray tubes, with voltages up to 320 kV
- Film and digital radiography
- Computed tomography with <5 micron resolution
- Energy-sensitive characterization including high-energy x-ray diffraction



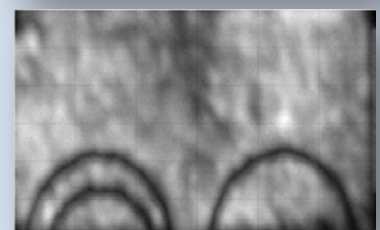
Thermal Inspection:

- Infrared camera, high resolution, high sensitivity, 640 x 512 array
- Flash lamps for traditional thermography
- Broadband, vibration source and laser vibrometers, and associated data acquisition and analysis for vibrothermography



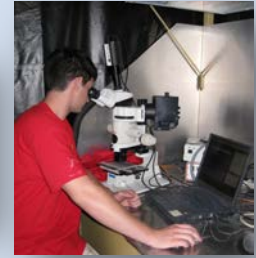
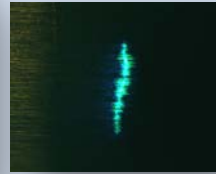
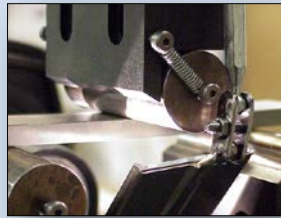
Terahertz radiation:

- Time-domain pulsed system from 50 GHz up to 4 THz at 5 GHz resolution
- Frequency-domain continuous-wave system ranges from 50 GHz to 1.5 THz at 100MHz resolution
- 4D gantry system for static spectroscopy and high-speed imaging in various geometric configurations



Magnetic Particle, Fluorescent Penetrant Inspection, and Supporting Instrumentation:

- Three magnetic particle systems with coil diameters from 12" to 24"
- Penetrant inspection and quantitative assessment for characterization of indications
- Surface and material characterization tools including optical microscopy, laser profilometry, and x-ray fluorescence
- Two mechanical testing systems for mechanical property measurement and sample fabrication



Current Sponsors: The IUCRC and complementary federal funded programs provide resources that are essential to the research, education and outreach functions of CNDE. Partners include the following:

- Air Force Research Lab
- Army Research Lab
- Federal Aviation Administration
- National Aeronautics and Space Administration
- National Science Foundation
- Areva
- Boeing
- Bell Helicopter (Textron)
- Cessna (Textron)
- DOE Los Alamos
- Knolls Atomic Power Lab
- Honeywell
- Pratt & Whitney
- Rolls Royce
- Spirit Aerospace
- Toyota Manufacturing

Annual Calendar of Events: While collaboration is encouraged throughout the year between CNDE staff and sponsors, there are a number of formal interactions that occur on an annual basis and include:

- Spring Sponsors meeting – typically held in mid-April to provide updates on technical progress and strategic planning for future initiatives
- Review of Progress in Quantitative NDE – International conference that includes over 200 papers and 350 participants that is organized by the CNDE staff. Provides an opportunity for informal discussions with sponsors
- Fall Sponsors meeting – typically held in mid-October to provide updates on technical progress and includes a short course